very closely after a violent cyclone; but in summer the weakest depression may produce a thunderstorm.

* * * * *

14. It is somewhat easy to forecast thunderstorms when the summer depressions appear over the southern regions of France; but it is much more difficult when a depression, over the Gulf of Gascony for example, suddenly disappears.

Although the pressure may be higher to the north, e. g., 770 mm. at Dunkirk, 765 at Mans, 760 at Biarritz, there is no cyclonic center. Under such circumstances the "cloud succession" alone furnishes a basis for a forecast. In fact, it is scarcely admissible that a depression should appear without a cloud accompaniment. If, in spite of the barometric rise, the cirrus, cirro-cumulus, alto-cumulus appear in regular succession, in the same direction from southerly points northward, and in spite of easterly winds, then it is infinitely probable that the cirro-nimbus will follow them in its turn. Therefore, even after the depression has disappeared, even in the case of a barometric rise (slight to be sure), even in the absence of the "squall zone" or of V-shaped isobars, yet the existence of a "cloud succession" would suffice to foretell the thunderstorm. Thus came in the too-famous thunderstorms of July 29, 1892, June 6, 1904, July 4, 1905, June 30, 1908, etc., all of which were characterized by an extraordinary violence in spite of the absence of sensible depressions and even in the face of high pressures with rising pressures. In fact these examples justify one in setting up the thesis that *the intensity of electric phenomena increases with the rise of the pressure.* A thunderstorm occurring in the summer with the barometer about 765 mm. will cause more ravages by rain, hail, or lightning than if the pressure had fallen to 755 or thereabouts.

15. [**D**] There is no occasion to introduce here hypothetical phenomena which, moreover, do not demonstrate anything: Such as the rapid descent of a sheet of air to the ground, or the precipitation of cirrus upon subjacent cumulus. The most attentive observation does not reveal any disturbance of this nature. The cooling frequently observed after the thunderstorm is often due to the change in the direction of the wind, a cyclonic phenomenon, and also to the sudden melting of a prodigious quantity of ice or snow crystals. The consideration of the vortical character of the squall offers a very simple explanation of the barometric variations and the fall in temperature as well as of the increase in cloudiness.

16. While the depressions of Gascony and the summer "cloud succession" of the south of France are the greatest sources of thunderstorms for almost the whole of France, there is yet another very remarkable thunderstorm formation, viz, the arrival of Saharan depressions upon the coast of Provence. As soon as a cyclonic center persists in that region, with cirrus and then cirro-cumulus from the SE. changing to E., we have to expect thunderstorms between the SE. and NE. throughout France accompanying winds from the east as well as from the west.[5]

* * * * *

17. To sum up, all thunderstorm forecasts should be based upon a simultaneous study of the barometric situation and of the cloud successions. The study of the isobaric map should lead to a forecast of the future pressure distribution, of the formation of depressions, and of squall zones for the next day. The study of the cloud succession ought to show whether or not *cirro-nimbus* should develop and also whether or not it will coincide with the depression centers on the morrow. The clouds indicate, better than do the depressions, the direction and speed of to-morrow's expected thunderstorm. On the day itself a station can determine this speed and direction only shortly before the arrival of the storm. [**E**] The consideration of the squall zone is insufficient, for its trajectory is indeterminant while the thunderstorm pursues a straight-line course, or at most a curve of very large radius, which neither the topography nor tidal movements nor even the manifold directions of the surface winds can deflect. Hail-falls and paths of destruction by tornadoes always make straight lines, which confirms these conclusions based on direct observations. Successive thunderstorms, even though each occupy the center of a slightly whirling movement having variable winds in all directions and with the lower clouds from an opposite direction, nevertheless advance in the direction indicated 24 to 48 hours previously by the upper clouds.

The thunderstorm, the *cirro-nimbus,* thus exist only in the higher levels, so that it is not possible to have any means of influencing either their direction or their effect. And yet the thunderstorm is of very limited duration, at most it may last 24 hours, generally a few hours suffice to exhaust it.

Perhaps the progressive descent of the upper clouds is a cause of its destruction. One has thus observed extensive thunderstorm clouds moving from S. to N. with lightning and thunder, dissipating, dissolving, even disappearing, with more or less observable delay, under the action of very dry winds from the N. or NE. The thunderstorm cloud subsists in the southerly current, but very probably experiences an evaporation as it attains the northerly current. The thunderstorm ceases while the thunderstorm cloud steadily fades away.

COMMENTS BY DURAND-GRÉVILLE.

[The foregoing paper by M. Guilbert called out the following comments by M. Durand-Gréville,[1] whose studies in thunderstorms, squalls, and hail have already been noticed here (1909, **37**: 237–239). References are to the passages marked by corresponding letters in M. Guilbert's paper.—C. A., jr.]

In a memoire "On the forecasting of thunderstorms," published in this volume, M. Guilbert puts forward his own ideas and rejects some of mine, which he has a perfect right to do; but he states my views in such a summary and fragmentary manner that the unwarned reader might not understand exactly what I hold in this connection. The present note designs less to present a fundamental discussion of our colleague's theory than to present our precise opinion concerning certain of the points that he discusses.

1. *Guilbert* says (**A**, p. 557):

The warmest days often fail to bring about any electric manifestation at all, and the warmest months are those most free from thunderstorms, as we have shown. The name "local thunderstorm" would appear to be more correct (than that of heat thunderstorm).

Durand-Gréville.—The thunderstorm is an electric disruptive discharge between the negative electricity of the earth's surface and the positive electricity of the cirrus region. The discharge does not take place unless a sufficient communication is established between the two levels. This communication is realized every time

[5] The direction of the thunderstorm cloud, cirro-nimbus, is often independent of the trajectory of the cyclonic centers and of the squalls, therefore also independent of the surface winds.—AUTHOR.

[1] Mise au point de quelques objections à notre théorie des grains et de la grêle. Assoc. franç. pour l'avance. d. sci., Compte rendu, 41me sess., Nîmes, 1912, Notes et Mémoires (Paris, 1913), p. 286-291.

when, over a limited region of the surface which is being strongly heated by the sun and in an atmosphere sufficiently warm and humid, there develops a cumulus with very lofty summit, which serves as the intermediary communication. Within the tropics, and chiefly over islands, ascending currents of warm, humid air develop every day in the warmest of the afternoon hours, hours when the thunderstorm bursts with regularity. Heat alone would not suffice to produce cumulus: for this reason thunderstorms are very rare in the very dry and very warm regions of the globe, even under the tropics. Thunderstorms that develop and remain in the same place deserve the name of "local thunderstorms." One should call them "heat and humidity thunderstorms" in order to bring out the double cause for the formation of cumulus. But since our senses perceive humidity much less readily than heat, particularly when the air is warm, one has fallen into the habit of calling them simply "heat thunderstorms."

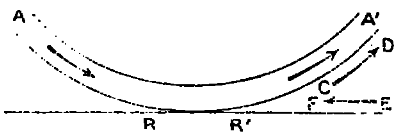

FIG. 1.—Arrangement of winds in a squall, after Durand-Gréville. (Vertical section.)

Heat thunderstorms occur in temperate regions also but much more rarely because there is much less chance of there realizing the conditions favorable for developing the extremely high cumulus. Nevertheless, the thunderstorm may readily develop in temperate regions if the summits of the less lofty cumulus (e. g. 5 to 6 km.) are put in communication with the higher levels by means of the descending sheet of air of the squall zone. [See fig. 1, *A*.] The thunder squall endures so long as the squall wind completes the communication between the cirrus region and the ground.

In passing may be here mentioned the extremely rare cloudless thunder squall with its tempest of dust. Clear cut examples of this storm have been found only in Australia, and it would seem to specially favor the production of ball lightning.

After these remarks it remains to point out that in our climates the immense majority of thunderstorms are those of the squall zone. To produce a thunderstorm there must first of all be a local cause: the presence of large clouds previously formed in a warm, humid atmosphere by ascending currents. But if they are to be extremely high these cumuli may exist throughout the whole day without bringing on the slightest thunderstorm. In order to produce the latter there must be a dynamic cause, viz, the passage of a squall zone (generally coming from a great distance) which establishes the communication between the two oppositely charged layers. Squall zones may exist at any hour of the day, ready to further the production of the thunderstorm. But one can see that their action would be more effective in the hours favorable to the building of great cumuli, i. e., during the warmest hours of the day.

Other things being equal, thunderstorms are most numerous and violent during the warmest months of the year. This fact is demonstrated by the thunderstorm statistics for all countries where there are a sufficient number of years of observations. If one compiles the data for a single year in a single country, even though it be as large as France, one might reach other apparent conclusions, which would disappear, perhaps, upon making a more profound examination.

For example, in M. Dongier's memoir "Les orages en 1907" we find that the number of thunderstorms observed from November to March has its minimum in January (115), its maximum in December (713); during the other seven months it varies from 2,166 (October) to 5,652 (May), with 4,489, 4,467, and 4,105 for June, July, and August. This result does greatly depart from the mean of the statistics. Evidently the number corresponding to the cold months is much smaller than that for the warm months. One may, however, ask whether the predominance of May is real. It is easy to find the answer to the question. At the beginning of his study M. Dongier observes that, throughout the greater part of France, the number of observers is still too small to furnish a guaranty that thunderstorms have not slipped unnoted through the meshes of the réseau. He does better, he mentions the names of 23 Départements where the guaranty of exactitude is sufficient. I have taken the statistics for the 23 Départements and the result was, as we anticipated, that August secured the preponderance to the detriment of May. Each may make the verification for himself.

Certain regions, the mountainous ones, form an exception to the rule. Corsica, for example, is richer in thunderstorms in winter than in summer. The explanation of the fact would be easy: the heating of the mountain flanks favoring the formation of cumulus; but this would carry us too far. Here it suffices to observe that, in our country as elsewhere, the winter thunderstorms are to be counted by hundreds, while the summer thunderstorms are in the thousands.

2. *Guilbert* says (**B**, p. 557):

According to M. Durand-Gréville himself, in the absence of cumulus, the squall zones would not be able to produce the thunderstorm. Therefore the squall can not serve for forecasting nonexistant thunderstorms, and far less for predicting the thunderstorms of to-morrow. Besides, the squall can not have more than an ephemeral existence. It would be rash to conclude that because present at one point it will pass over some other region after a determined delay, and all the more so because its speed is not known.

Durand-Gréville.—Observation proves that the squall zone by itself (save the almost unique Australian case) can not produce the thunderstorm. Observation also shows no less clearly that a large cumulus, or even a cumulo-nimbus (i. e., a cumulus draped with a mushroom head of cirrus, otherwise the "cirro-nimbus" of M. Guilbert)[2]—disregarding the, for us, very rare case where its summit is lofty enough to almost attain the region of the upper cirrus—will remain inert during many hours and not become the seat of disruptive electric manifestations until the precise moment when the descending sheet of a squall zone, which likewise produces at the same instant the "squall hook" in the barogram, shall have brought the summit of the cumulus into electric communication with the positively charged region of the cirrus.

As for the forecasting, it takes on two different forms, according to the manner in which the existence of the squall zone is recognized. When the zone is still over the Atlantic, as revealed by the pattern of the isobars, its arrival over the continent may be predicted with a degree of probability equal to that of the arrival of the depression of which it forms an integral part. With this degree of probability one may forecast the development of squall winds at all those points on the continent which will be swept by the squall zone as it marches parallel with itself from west to east. One ought to add that its passage will release rains at all those points where the atmosphere may be sufficiently charged with clouds and that thunderstorms will occur at all points, less numerous now, where the clouds shall have sufficiently lofty summits. But since one does not know whether the depression is moving or not, one will not be able to say precisely the hour when the wind squalls will develop at this or that station. Nevertheless one may estimate, from the mean speed (30 km. per hour) of displacement of depressions,

[2] Compare, among others, *W. J. Humphreys:* Unusual display of false cirrus. Bull., Mount Weather Observatory, 1909, v. 2, pt. 3, p. 133–5.—C. A., jr.

an approximation to the probable time when the squalls, with their probable cortège of rains and thunderstorms, will appear over the continent, as well as the times of transit for more easterly points.

The situation is altogether different if the effective presence of a squall zone on terra firma is reported telegraphically to the Bureau Central, which from that moment on would be able to keep in touch with its passage over all the points successively swept by the wind of the squall. Two or three hours would then suffice for the bureau to recognize the orientation and speed of displacement of the squall zone (just as the railways keep track of the progress of a train), and it would be able to advise points farther east of the exact time, to within 15 minutes, of the passage of the squall and some hours in advance. The regions thus warned could then judge, from the local state of the atmosphere above them, whether they were merely threatened with a tempestuous wind or also with downpours and thunderstorms at the hour indicated by the Bureau Central.

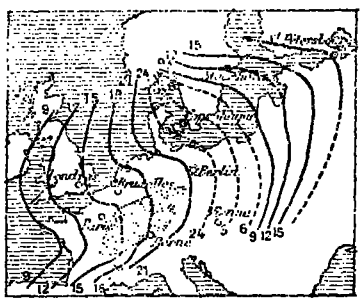

FIG. 2.—Successive positions of the "squall front" of Aug. 27–28, 1908, and the districts visited by the thunderstorm (indicated by stipple).

Unfortunately there is nothing "ephemeral" about the squall zone. It often endures for 24 hours, sometimes for 48 hours or more [see fig. 2], and travels from the Atlantic to Siberia. Its speed varies with that of the depression, an integral part of which it is, but when it has once entered the continent from the Atlantic there is nothing easier than to learn telegraphically the slight variations in its speed and to allow for them in the warnings. It would suffice were the Bureau Central authorized to receive gratis each month and at any hour of the day several hundred additional telegraphic reports. By this means it could organize a service of forecasts that would not be vague and contingent in character, but state precisely the passage at this or that hour at each point, of a tempestuous wind threatening a thunderstorm and—what is more important—a hail fall at the same time. This very simple system of warnings, which I have urged since 1894,[3] is in course of being organized beyond our borders. If we fail to take the necessary measures it will again come to pass that a French discovery will have found its practical application abroad before being taken up in France. No doubt the main thing is that it be initiated somewhere, because the results it will give will then overcome opposition everywhere; but—.

3. *Guilbert* says (**C**, p. 558):

In general the showers, rains of short duration, often abundant and sometimes torrential, are due to the passage of a cirro-nimbus. Therefore one should announce thunderstorm showers, not showers.

[3] In this REVIEW, June, 1898, 26: 256, Prof. Abbe suggested that all telephone and telegraph stations within 50 miles and on the NW. and SW. of cities like New York, Philadelphia, be organized into a system for reporting thunderstorms to those cities. In 1897 he had prepared a preliminary map (this REVIEW, April, 1899, 27: 157) of such stations within 100 miles of Washington, and had found that any thunderstorm 5 miles in diameter would always slip through unnoticed from the NW. and rarely be detected from the W., N., SW., or S. To catch all tornadoes the stations would have to be not more than a mile (2 km.) apart. He has repeatedly advocated such a system as M. Durand-Gréville describes.—C. A., jr.

Durand-Gréville.—All lofty cumulus is necessarily made up of a lower portion whose droplets are above 0° C., of a middle portion where the droplets are in an undercooled state, and of a superior portion where they have become ice particles. The mushroom cumulo-nimbus is nothing more than a great cumulus whose superior portion has been fortuitously converted by a very strong ascensional current into a cap of cirrus separated from the body of the cumulus.[4] (This is the cloud which M. Guilbert, logically enough, calls a cirro-nimbus and which he considers to be made up wholly of snow crystals.) When the violent descending wind of a squall zone encounters a cumulo-nimbus of this character it demolishes the stable structure, the ice crystals meet the undercooled drops, and by incorporating the latter form the rudimentary hailstones, which continue to grow during their fall through the undercooled drops. There follows a fall of hail unless the hailstones are melted by the warm air they fall through, in which case the only result is a fall of rain. Electricity has nothing to do with the production of either the hail or the rain falls. We often have showers without a thunderstorm. But, as pointed out in section 1 (p. 559), since the existence of a lofty cumulus, together with the passage of a squall zone, are the double condition requisite for the production of a thunderstorm, therefore it follows that the shower and the thunderstorm are often concomitants, though neither is the cause or the effect of the other, a circumstance that has created the existing confusion of ideas.

4. *Guilbert* says (**D**, p. 559):

There is no occasion to introduce here hypothetical phenomena which, moreover, do not demonstrate anything; such as the rapid descent of a sheet of air to the ground, or the precipitation of cirrus upon subjacent cumulus.

Durand-Gréville.—The very narrow squall zone, rarely wider than 10 to 50 km., is throughout its length the seat of extraordinarily violent, often tempestuous winds blowing from directions averaging between W. and NW. Throughout its length the zone is bordered on either hand by weak or very weak winds, usually from the SW. It is logically impossible to admit that along a stretch of 1,000, 2,000, or even more kilometers, the weak or very weak surface wind prevailing behind the squall zone is able to feed the violent, even tempestuous surface wind within the zone; and, conversely, that the violent surface wind of the squall should feed naught but a weak surface wind or a calm in front, particularly in view of the fact that this weak surface wind has the opposite direction, as sometimes happens. It is, therefore, absolutely necessary that the squall wind should be fed from its rear by masses of obliquely descending air, and that these air masses, after having swept the ground through the breadth of the zone, should remount obliquely from that zone toward the upper regions of the depression. That excellent observer, Plumandon [of Clermont-Ferrand, France], while not seeking to establish the cause of the phenomenon, or at least not suspecting it, pointed out over 20 years ago that the cirrus-topped, mushroom cumulus [mushroom cumulo-nimbus] does not begin to produce hail until the precise moment when its summit "begins to disintegrate." In this well-established, observed fact we have the unexceptionable proof that the broad sheet of the squall wind descends from altitudes at least as lofty as those of the highest cumulo-nimbus, i. e., that it is fed by a portion of the variously sloping upper layer of air masses ascending at the center of the depression. We simply set these considerations over against M. Guilbert's

[4] Compare W. J. Humphreys, op. cit.

theory, which requires that the squall wind be "produced by" the cirro-nimbus, just as also are the tornado (la trombe), the hail and the thunder storm. Our theory, based solely on observed facts and their direct interpretation, has the advantage of explaining why the squall wind develops without discontinuity throughout the length of the squall zone, even at those points where there does not exist any cloud, either cirro-nimbus or other kind.

5. *Guilbert* says (**E**, p. 559):

The consideration of the squall zone is insufficient, for its trajectory is indeterminate, while the thunderstorm pursues a straight-line course. * * *

Durand-Gréville.—Numerous verifications long since proved to M. Durand-Gréville that all points on the squall zone, moving along with the depression of which they are a part, follow paths parallel with that of that depression. The clouds carried along by the squall wind when it reaches them, follow a similar course scarcely modified by the component added by the direction (W. or NW.) of the squall wind. The displacement of cloud masses under the action of the squall, scarcely exceeding some tens of kilometers, their trajectory is sensibly rectilinear. Durand-Gréville has not only constantly affirmed the fact of the rectilinear movement of thunderstorms *over short distances*, but has stated the same truth with reference to the tracks of discharges of rain or hail and of tornadoes (trombes). He early pointed out, further, that this path is almost parallel with that of the low center, having a similar direction and a speed equal to that of the center. He thus has shown that, far from being indefinite, the advance of the squall zone and of all its attendant phenomena is absolute in form, in orientation, in direction, and in velocity.

A BREATHING WELL.

Under date of November 29, 1915, Mr. John Free, of New Carlisle, Ohio, sent the following account to the Weather Bureau office in Columbus, Ohio:

I have a well that puzzles our mind. It will blow out air and also take in air at different times. I have noticed this for two years. When it blows out it is an indication of rising temperature, wind, and rain. When it takes in air it denotes fair weather and falling temperature. The well is covered with cement and has a wooden pump. At the side of the pump we left a space of 14 by 4 inches for the frost pin to work back and forth. So we put a block in the space to keep the mice out, and when it blew out it sounded like steam escaping. So I thought it would blow a 10-cent horn. So I bored a hole in a block and placed the horn in the hole and it did blow. I have heard it blow for 48 hours without ceasing; and also saw it take in air for just as long. On the 26th [November, 1915?] it blew air out and it rained. On the morning of the 27th it was taking in air all day. On the next morning (28th) it blew out very strong. At 3 p. m. it was raining.

Can you explain that; did you ever see or hear of the like?

In his reply, Prof. J. Warren Smith points out that this "breathing" of wells and caves is well known to many students, although it must often escape the attention of persons less keen than our correspondent. As the reply pointed out, the phenomenon is causally related to the escape of fire damp and other gases in mines, to the variations in the flow of springs, the roiling of well water,[1] etc.

A storm center, or area of low pressure, is preceded by a region of falling atmospheric pressure, and while a locality is under the influence of this region of rapidly falling pressure the air and other gases within the earth's crust are partially released from the pressure confining them. They then tend to escape through the crevices and at the same time may press outward the waters feeding springs and wells. Thus the water in wells tends to rise, springs to flow copiously, mines and caverns to give forth air and gases during the falling pressure which precedes and accompanies the bad weather of storm centers.

Behind a storm the atmospheric pressure is increasing, thus just reversing the above processes; and under the action of the more pronounced high-pressure areas air may perhaps be even pressed into the earth's crevices. Thus the clearing and (in winter) cooling weather that precedes and accompanies anticyclonic areas would be announced by an inbreathing of such a tightly covered well as the one described above.—C. A., jr.

[1] See "Wells and storms," this REVIEW, July, 1900, 28: 293.

A TEMPERATURE INVERSION IN THE GRAND RIVER VALLEY, COLORADO.

By E. S. NICHOLS, Local Forecaster.

[Dated: Weather Bureau, Grand Junction, Colo., Dec. 9, 1915.]

In the Grand Valley of western Colorado on the morning of January 7, 1913, occurred so remarkable an inversion of temperature that special attention should be called to it.

The main portion of the Grand Valley is a southward and southwestward sloping plain on the northern side of the Grand River, and extending from the foothills of Grand Mesa 50 miles or more to the Utah line and beyond. The Weather Bureau maintains several cooperative stations in the southeastern or upper half of the valley, in addition to the regular station at Grand Junction which is about 12 miles from the upper end. All the stations referred to are equipped with Weather Bureau pattern maximum and minimum thermometers, which are exposed in instrument shelters of Weather Bureau design. At the cooperative stations the thermometers are about 5 feet above ground; while at the Weather Bureau office in Grand Junction they were, on the date in question, at a height of 44 feet above ground. The relative positions of the stations are shown in figure 1, which also gives elevations above sea level, closely approximated when not known exactly, of those that reported for the date mentioned.

In general, in this upper half of the valley, the ground slopes to the river banks on the north side of the Grand, while on the south side of that stream low bluffs rise from the water's edge or a short distance therefrom. Back of the bluffs in the upper fourth of the valley the ground is in general a nearly level bench or terrace known as "Orchard Mesa," except in the extreme upper end of the valley where the ground is at first rolling but soon merges into the foothills of Grand Mesa.

On the morning of January 6, 1913, the weather map showed the northern side of a low-pressure area over southwestern New Mexico; while high-pressure centers with maximum sea-level barometer readings above 30.6 inches and 30.8 inches, respectively, overlay the Snake River Valley and the east-central portions of the Dakotas. At Grand Junction that morning the sky was cloudless, temperature reached $-6°$F., dew point was $-9°$, and the southerly wind was light; temperature rose to a maximum of 11° during the day, which was practically cloudless and had 100 per cent of the possible sunshine.

On the morning of the 7th the southwestern disturbance had disappeared and the western peak of high pressure, with a central barometer reading above 30.6 inches,